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Influence of vein fabric on strain distribution and fold kinematics

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Abundant pre-folding, bedding-parallel fibrous dolomite veins in shale are found associated with the Nkana-Mindola stratiform Cu-Co deposit in the Central African Copperbelt, Zambia. These monomineralic veins extend for several meters along strike, with a fibrous infill orthogonal to low-tortuosity vein walls. Growth morphologies vary from antitaxial with a pronounced median surface to asymmetric syntaxial, always with small but quantifiable growth competition. Subsequently, these veins were folded. In this study, we aim to constrain the kinematic fold mechanism by which strain is accommodated in these veins, estimate paleorheology at time of deformation and investigate the influence of vein fabric on deformation during folding. Finally, the influence of the deformation on known metallogenetic stages is assessed.

Various deformation styles are observed, ultimately related to vein attitude across tight to close lower-order, hectometre-scale folds. In fold hinges, at low to average dips, veins are (poly-)harmonically to disharmonically folded as parasitic folds in single or multilayer systems. With increasing distance from the fold hinge, parasitic fold amplitude decreases and asymmetry increases. At high dips in the limbs, low-displacement duplication thrusts of veins at low angles to bedding are abundant. Slickenfibres and slickenlines are sub-perpendicular to fold hinges and shallow-dipping slickenfibre-step lineations are parallel to local fold hinge lines. A dip isogon analysis of reconstructed fold geometries prior to homogeneous shortening reveals type 1B parallel folds for the veins and type 1C for the matrix.

Two main deformation mechanisms are identified in folded veins. Firstly, undulatory extinction, subgrains and fluid inclusions planes parallel the fibre long axis, with deformation intensity increasing away from the fold hinges, indicate intracrystalline strain accumulation. Secondly, intergranular deformation through bookshelf rotation of fibres, via collective parallel rotation of fibres and shearing along fibre grain boundaries, is clearly observed under cathodoluminescence. We analysed the internal strain distribution by quantifying simple shear strain caused by deflection of the initially orthogonal fibres relative to layer inclination at a given position across the fold. Shear angle, and thus shear strain, steadily increases towards the limbs away from the fold hinge. Comparison of observed shear strain to theoretical distribution for kinematic mechanisms, amongst other lines of evidence, clearly points to pure flexural flow followed by homogeneous shortening. As flexural flow is not the expected kinematic folding mechanism for competent layers in an incompetent shale matrix, our analysis shows that the internal vein fabric in these dolomite veins can exhibit a first-order influence on folding mechanisms.

In addition, quantitative analysis shows that these veins acted as rigid objects with high viscosity contrast relative to the incompetent carbonaceous shale, rather than as semi-passive markers. Later folding-related syn-orogenic veins, intensely mineralised with Cu-Co sulphides, are strongly related to deformation of these pre-folding veins. The high viscosity contrast created by the pre-folding fibrous dolomite veins was therefore essential in creating transient permeability for subsequent mineralising stages in the veining history.